Innovations in American Government Award Winner, 1995
Aerospace Guidance and Metrology Center, Newark AFB, Ohio
U.S. Department of Defense
Ozone Depleting Chemical Elimination

Report on Technical and Managerial Innovation

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Aerospace Guidance and Metrology Center
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Preface

The Aerospace Guidance and Metrology Center (AGMC), at Newark Air Force Base in Ohio, was once one of the largest single-site users of ozone-depleting chemicals in the world, but the threat posed by these chemicals to the Earth's ozone layer prompted the facility to phase them out. The complexity of the work done at the Center would have made even a gradual phase-out tremendously difficult, but AGMC completed the process of adopting alternative technologies in a short time (mainly between 1992 and 1994). The speed with which AGMC found alternatives that met its requirements demonstrates the success of its technical and managerial innovations.

Many organizations have already benefited from the technical innovations developed by AGMC. The Center has hosted government and industry representatives from the United States and foreign nations, and it has served as an information source on new ozone-protective technologies. However, as of October 1996, Newark AFB will cease to be part of the United States Air Force. It is one of the military sites chosen by government to be ''privatized in place," and industry will take over the site. The resulting changes in the Center's mission and structure will reduce its ability to disseminate information on technology transfer. The purpose of this report is to document the Center's accomplishments in this field.

The Center and the author wish to thank the Ford Foundation, the Kennedy School of Government, and the Council for Excellence in Government for their support of this project. In 1995 the Center was selected as a finalist in the Innovations in American Government Program of the Ford Foundation and the Kennedy School. A grant for this report was provided by the Foundation, and project administration for the grant and report was provided by the Council. The author also wishes to thank everyone at Newark for their assistance and hospitality and especially his on-site points of contact, Mr. Tesfa Abraha and Captain Vernon Milholen.

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Introduction

The Aerospace Guidance and Metrology Center (AGMC), at Newark Air Force Base in Ohio, has been providing maintenance support for the United States military forces since the 1960s. During the Cold War period, its work in support of the nuclear deterrent required secrecy, so the functions of the facility -- and even its very existence -- were not widely known. Local residents attributed a variety of possible functions to the base: some thought it was a launch site for nuclear missiles or even a location for holding flying saucers and aliens captured by the Air Force.

In fact, Newark Air Force Base maintained missile and aircraft navigation systems. The Center in its 1995 Financial Report explains that "the AGMC Directorate of Maintenance is an AFMC Industrial Complex engaged in depot level repair, overhaul and modification of navigation systems used by virtually every missile and aircraft to assure that each arrives on target, on time, and on command." It performs these services for all components of the Department of Defense. The primary responsibilities of AGMC are to test and repair inertial navigation and guidance systems which direct missiles and aircraft to their targets: "Composed of gyroscopes and accelerometers mounted on stabilized platforms, and controlled by computer, inertial systems are immune to jamming and other outside interference." [1]

AGMC is also a technology repair center for nine models of displacement gyro: "This particular type of gyro is a component of an aircraft's integrated flight director system and functions as a master flight reference control, providing directional reference in azimuth and an attitude reference in pitch and roll. The displacement gyro workload supports aircraft deployed throughout the United States and the world for all three services." [2]

The Directorate of Maintenance at AGMC is composed of a staff office and three divisions -- Aircraft Product, Engineering, and Missile Product. Inertial guidance and navigation system repair operations are housed in a 13-acre, wide-span steel building with 294,724 square feet of environmentally controlled areas. The Directorate has a workforce of about 800 highly skilled personnel, and other base functions have a workforce of about 700 individuals, 200 in metrology and 500 in various other support functions.

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[1]"Mission responsibility of this Center currently encompasses inertial guidance system repair and ibration support for Minuteman III WS-113B-NS-20, the Peacekeeper, the Carousel IV-E, the AN/ARN- Inertial Measurement Unit , the LN-39 Inertial Navigation System for the A10 and F16, the B52 G/H F117A Standard Precision Navigator/Gimbaled Electrically Suspended Gyro Aircraft Navigation tem(SPN/GEANS) and the B-1B Inertial Navigation Unit."

[2]"For the Navy repairs are made to the Dual Miniature Inertial Navigation System (DMINS) talled in CVS and CVNS class ships. The Control Display Units, Bus System Interface Units (BSIU) Fuel Savings Advisory System are also repaired. Recently responsibility has been assumed for the g Laser Gyro for the F15, F16, and C130 and Advanced Cruise Missile (ACM) navigation control set sensor."

Introduction

Throughout the 1960s and 1970s AGMC was one of the largest single-site users of ozone depleting chemicals (ODCs) in the world. Its proactive and rapid elimination of ODCs and development of alternatives in the 1990s provides an example for other governments and military forces of technical and managerial innovation of the highest calibre. Before the alternatives were adopted, it was not unusual for AGMC to use 2,000,000 pounds of chlorofluorocarbons per year, in about 1,100 different uses. If no action had been taken to replace the ODCs, AGMC would have had to stockpile huge quantities of them to meet its needs, at a cost as high as $6,000,000 at 1995 prices. The cost of currently used alternative processes is estimated at $200,000 a year. The innovations at AGMC resulted in a savings of over one order of magnitude, with a payback of less than one year.

In October 1995 AGMC's achievements were recognized by an award for innovation from the Ford Foundation and the Kennedy School of Government.

Method

This report is based on documentation provided by AGMC and on a series of interviews and informal discussions there. It consists of a number of sections, most of which can be read independently of each other. The report and the documents it refers to will be of interest to organizations requiring technical assistance in developing ODC-free cleaning processes.

More detail can be found in transcribed taped interviews, all of which are in the possession of the Council for Excellence in Government, Washington, D.C., and the author, Jonathan Linton (416-488-9562), Department of Management Science, Schulich School of Business, York University (Toronto). Interviews have been linked to qualitative analysis software, which makes possible further research into innovations at AGMC. A copy of the original interview tapes will be held until at least December 31, 2001.

Data were collected during three visits: November 27-December 1, 1995; December 11-15, 1995; and January 23-26, 1996.

Taped interviews were conducted with:

Tesfa Abraha Point of contact on a number of projects
conducted by Battelle
Project Engineer Laboratories, Columbus, Ohio; a key
player in conservation and control efforts.

Angelo Ambrose Manager of Missile Division, to whom all technicians
and process
Missile Division engineers involved with repair and
refurbishment of Missile Guidance systems report.

Jerry Anderson Manager of Methods, Engineering and Physical
Sciences
Engineering Laboratories and other areas that supported the
ODC-elimination project; second-level supervisor of all project engineers;
former chief scientist.

Capt. Bob Campbell Worked on process development and
implementation, the focal
Project Engineer point for new process
implementation.

Chuck Davis Worked with project engineers on fixture design
and in training on
Trainer new ODC-alternative cleaning technologies.

Don Durbin Supervisor of the Engineering and Methods Laboratory;
was
Engineering and responsible for all ODC-elimination
project engineers and two
Methods Laboratory trainer/technicians.

Pat Drum Point of contact for provision of on-site supplies to
the ODC-

Logistics elimination project.

John Engelmann Provided testing services for testing in-house
work, including
Chemistry Laboratory distillation and processi ng of waste chemicals.

Tim Geinger Process engineer in Missile Division.
Process Engineer

Mark Gwinn Process engineer in Missile Division.
Process Engineer

Winnie Greulich Technician in Clean Room 7 during implementation
of new
Technician processes.

Dave Hickle Process engineer in Aircraft Division.
Process Engineer

Tom Huber Supervisor of pipe fitting a key task in facilities
preparation and part
Pipe Fitting of the Civil Engineering function.

Don Hunt Original program management support, deeply involved
with ODC-
Chief Scientist elimination for more than ten years.

Lt. Col. Stan Hunt In charge of the directorate that provided
all facilities modifications
Civil Engineering for the new processes.

Julie Imes Point of contact in Purchasing; obtained
supplies not available on-
Contracting site.

Madeleine Johnson Point of contact for several projects conducted
by Battelle
Project Engineer Laboratories, including eli minating
ODCs from many test chambers.

Capt. George Letourneau Handled the administrative tasks associated with the
program,
Project Engineer including coordination and creation
of cleaning process database.

Rick McDonald Point of contact responsible for most plumbing
requirements
Pipe fitter for the program.

Capt. Vernon Milholen Worked on conservation, use reduction and tracking;
point of
Project Engineer contact for documentation.

Mike Miller Worked with project enginee rs in training
technicians on new ODC-

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Trainer alternative cleaning technologies.

Gerry Moore Supervisor of process engineers.
Engineering Supervisor

Gene Ott Worked on aqueous process development and
implementation.
Project Engineer

Gail Pellet Point of contact in Finance and Budgeting
for ODC-alternative
Budget Office cleaning processes.

Vince Powers Point of contact in Environmental Management;
responsible for
Environmental permits and reporting env ironmental measurables.

Management

Col. Joseph Renaud Base commander during the time that most of the
work was
Base Commander accomplished.

Mike Scholl Responsible for ensuring that facilities and
processes met health and
Safety Officer safety regulations.

Greg Sites Refrigeration technician involved with the
changeover to non-ODC
Technician refrigerants in environmental chambers .

Tony Skufca Director in charge of all navigational guidance
system repair and
Maintenance Director testing work during implementation of new
processes; third level supervisor of engineers and technicians.

Gary Stickle Technician in Clean Room 3 during
implementation of new
Technician processes.

Dewey Wells Supervisor of several clean-rooms during
transfer to ODC-
Cleanroom Supervisor alternative cleaning technologies.

Charlotte Wilson Point of contact for provision of on-site
supplies to ODC-
Logistics elimination project.

Sharon Wilson Technician in Clean Room 12 during the
implementation of new
Technician processes.

Telephone interviews were also conducted with personnel outside the base, including:

Method

1. Bob Rogahn, Delco, Kokomo, IN
2. Bob Prause, Battelle Laboratories, Columbus, OH
3. Floyd Rami, US Air Force, Ogden, UT
4. Larry Olsen, US Air Force, Ogden, UT

Overview of Technology and Technical Innovations

The Aerospace Guidance and Metrology Center (AGMC) has eliminated the use of ozone-depleting chemicals (ODCs) in cleaning over 1,100 precision navigational and guidance system components. The components are made from a wide variety of metals and epoxies. The first components cleaned with ODC-free processes have been in use since the late 1980s. The rate of field failure of these components, as compared to those cleaned with the original ODC processes, has declined since the start of the ODC-elimination program. (It is not possible to credit this decline wholly to changes in the cleaning processes, because many improvements to the gyroscopes have been made concurrently.)

The goal of AGMC was to convert all cleaning processes to aqueous cleaning. Where this was not possible, an alternative solvent could be used, but not even low ODCs were considered as potential alternatives. The aim was to choose chemicals and processes that would be the least likely to create health, safety or environmental risks in the future. AGMC wanted to protect employees and the environment and to minimize the need to go through a painful process of finding new methods in the future.

Complexity of Cleaning

Cleaning is a very complex process. Few people attempt to understand all its fundamentals and no one is really sure how clean a component needs to be to meet its field requirements, because quantitative cleanliness requirements have never been established. But if people attempted to understand cleaning from its first principles, they might never reach the point of trying to clean anything. They might even decide that more effective cleaning processes are undesirable, because as a colleague suggested to Captain Campbell "one might remove helpful contaminants of unknown composition which are not presently believed to exist."

A theoretical approach to the problem of finding a precision cleaning solvent for guidance system components would pose a question this way: what is required to remove a spherically-shaped contaminant from a flat surface? The theoretical answer would be a more aggressive process than those which have been acceptable historically. Consequently, AGMC took a practical approach and focussed attention on observing what actually happens to contaminants during cleaning. Battelle Research Laboratories were commissioned by AGMC to prepare a methodology to measure cleaning effectiveness. The procedure they developed involves:

1. Applying a known quantity of a known contaminant to the material surface
2. Treating the test piece with the cleaning process
3. Examining the quantity of known contaminant remaining on the test piece and the quantity removed from it. [3]

[3]Additional details can be found in *Methods for Improvement of the Stable Isotope Cleaning formance Evaluation Program*, September 1993, Battelle, and in *A Method for Cleaning Performance luation Using Stable Isotopes*, August 1992, Battelle.

The expression *If at first you don't succeed, try, try again* applies to cleaning processes. There are a huge number of variables that may lead one to reject acceptable solvents or processes prematurely. A number of these variables are discussed in this section.

Contamination

Contamination is a primary concern in cleaning processes. A tiny particle of contaminant is sufficient to cause field failure. The effect of the contamination is neither consistent nor controllable, so it can cause failure at any time. Guidance system components are therefore refurbished in a clean-room environment.

One plan at AGMC was to have a central cleaning station during the development phase of the ODC-elimination program. A seven-stage process was proposed:

1. Dismantle the gyroscope in the clean room.
2. Transfer parts in a sealed bag to a cleaning station in a clean room.
3. Open the sealed bag at the cleaning station.
4. Clean the part.
5. After cleaning, pack the part into an other bag and seal the bag.
6. Transport the part back to the clean room.
7. Open the bag in the clean room and remove the clean part.

This procedure was found to be unacceptable. It was possible to provide packaging that would protect parts from dust and humidity while in transit, but breaking the seal on the packaging could allow some of the polymer in the packaging to be transferred to the surface of the parts, thereby contaminating them. To reduce the chance of contamination from the packaging material, the procedure was modified so that tear-down, cleaning and reassembly were conducted in the same area.

Another major concern was static electricity. The potential for static electricity to contribute to contamination was demonstrated by chief scientist Don Hunt using a simple experiment.
First he ensured that he was carrying a static charge. Then after placing a surgeon's glove on his hand, he picked up a metal component and held it directly over a full ashtray. The component was lowered, but not allowed to contact the ashtray. As the component approached the ashtray, it was possible to see movement in the ashes. The static charge was transmitted, through the glove, from his hand to the component and it attracted the ashes to the component. The moral of the experiment is : *that static charges attract harmful contaminants to sensitive components*

In the clean room, the technicians use a compressed air gun to blow across components to assist in drying or to change the components' surface temperature. Unless it is treated, this air stream will carry a static charge that will lead to additional contamination. Standard antistatic procedures were adopted in the clean room. It is important to ensure that all potential sources of static electricity are eliminated.

Material Compatibility

The compatibility of the materials to be cleaned and the cleaners to be used on them and the compatibility of the cleaners with the environment in which they are used are key issues in cleaning. First, one must identify all the materials to be cleaned and all the materials to be used in cleaning. Then, it is necessary to contact sources of expertise and obtain information on exactly what is compatible with these materials and what is not.

Beryllium a stable metal under normal conditions, but is a highly reactive metal if it is placed in certain cleaning environments. An extremely violent reaction will occur if beryllium is placed in a mixture of methanol and chlorofluorocarbons, two standard cleaners. Many technical personnel believed that beryllium components could not be cleaned with water. But beryllium is highly reactive only in certain environments.

It was discovered that the reactivity of beryllium also depends on how the beryllium was manufactured. At AGMC, beryllium in various components was supplied by three different firms. The same alloy from different firms had different compatibilities in different environments.

A similar phenomenon is observable with respect to epoxies. The possibility exists of differences in compatibility with specific cleaning environments for different brands, types and formulations of epoxies. And the temperature at which an epoxy is cured has an effect on its compatibility with specific cleaning environments. In general, the lower the original epoxy cure temperature, the greater the tendency of the epoxy to soften when placed in an elevated temperature for cleaning.

It is important to have access to what is currently known about the compatibility of all the materials involved in the cleaning process. The following compatibility issues should be considered:

1. Compatibility between a component and the specific cleaning environment it is placed in.
2. Possible differences in compatibility due to variations in the formulation or processing of a material. [4]

AGMC had to study the compatibilities of:

- Ferrous alloys
- Stainless Steel

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[4]For additional information on AGMC's experience with materials compatibility see *T-1B SG and TG End Housing Aqueous Cleaning Project, Summary to Date*, July 1990, by Thomas Ciupak, C; *Experimental Evaluation of the Corrosive Potential of Flux Residue Cleaning Agents*, January 2, Battelle; *Experimental Evaluation of the Adhesive Degradation Potential of Aqueous Cleaning cesses*, January 1993, Battelle; *Metal-Detergent/Cleaner Compatibility*, January 1994, Battelle; *ernatives to Ozone Depleting Chemicals (ODC) Dependent Test Equipment Components: Topical Repo. erials Compatibility*, September 1993, Battelle; and *Experimental Evaluation of the Adhesive radation and Corrosion Potential of Silicone Fluids*, January 1995, Battelle.

- Aluminum
- Beryllium
- Copper
- Gold
- Pivot Jewels
- Epoxies
- Beryllium Copper
- Cartridge Brass
- Chromium Copper

Cleaning with Water

It is misleading to say simply that water is used as a cleaning solvent, for there are different grades of water. Obtaining pure water is a common problem for organizations considering the use of water as a solvent in precision cleaning. At AGMC, the criticality of water purity took several years to be appreciated. The components first cleaned at the center were not difficult to clean, so water purity was not an issue. But as work proceeded, it was realized that water purity had to be improved. The water that is now used at AGMC is ultra pure water, an extremely pure grade of deionized water. But deionized water is "hungry water": it absorbs ions of any metals exposed to it, and the resulting ion solution is impure. There are many factors to consider when working with deionized water:

1. Exposure of water to air will allow oxygen to dissolve into it.
2. The oxygen content of water increases if it is agitated in the presence of oxygen.
3. The presence of ions and gases reduces the value of water as a solvent for precision cleaning.
4. The solubility of oxygen in water varies inversely with temperature.
5. The addition of cleaners or salt decreases oxygen's solubility in water.

A number of factors must be considered when using water and detergent as a precision cleaning system:

1. Raw tap water or ground water is a mixture of water, minerals in solution, particulate, ions, and gases. A purification plant, specific to local water composition, must be established for the water supply. The purity of deionized water is a critical factor in successful cleaning.
2. Methods of disposing of waste water vary with jurisdictions. Treatment of waste water must meet the guidelines of the area in which a cleaning facility is located.

3. There is a wide range of detergents available. Different firms offer alternative formulations, and there are different categories of detergents. AGMC found that detergent suppliers were able to offer significant assistance in finding suitable detergents.

Once the requirements of minimizing contamination, insuring material compatibility, and purifying the water supply were satisfied, a substantial number of experiments were conducted to test variables such as: time in cleaning bath, water temperature, detergent type, concentration of detergent, and the use of ultrasonic vibration.

Cleaning components with water and detergent posed several additional challenges. To prevent flash rusting and water spotting on metal surfaces, water had to be removed immediately from the components as they left the cleaning process. Removal of water became a two-step process accomplished by using purified compressed air to blow water off the components and then baking-off residual moisture in a nearby vacuum oven.

It was also necessary to provide support for the components (fixturing) that would allow water and detergent to reach all their surfaces but not scratch or dent them, by contact with other parts. Designing suitable fixtures was a significant task at AGMC, which had a workload of over 1,100 different components.

Degradation of inertial instrument fill fluid was another area of concern at AGMC. Polybromotrifluoroethylene and polychlorotrifluoroethylene react with water to form acids. The formation of acid in a guidance system assembly is unacceptable, due to its corrosive effects. It was critical that all components be completely dry before they were reassembled. [5]

Identifying Degradation Caused by Alternative Processes

During the Cold War, when the guidance systems were built, state-of-the-art cleaning processes were chosen. But all their specifications referred to the use of specific ODCs, and suggested no procedures for changing the solvents to be used in cleaning processes.

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[5] Additional details on infrastructure, equipment and processes are available in *Degradation of ybromo Fill Fluid*, December 1992, Physical Science Laboratory AGMC; *The Cyl-sonic Cleaner: Aque rasonic Cleaning Using Biodegradable Detergents*, July 1988, Kenneth Patterson and Don Hunt, AGMC; *eous Cleaning of Instrumentation Bearing Assemblies*, January 1990, Gene Ott, AGMC; *GIT-1B and TG ' Housing Aqueous Cleaning Project: Summary to Date*, July 1990, Thomas Ciupak, AGMC; *Precision rings Cleaned at AGMC*, July 1991, Ray Vargas, AGMC; *Aqueous Cleaning for Precision Bearings and yllium*, November 1991, Don Hunt, Gene Ott, Thomas Ciupak, and Ray Vargas AGMC; *Aqueous Alternati CFC-113 and MCF for Precision Cleaning of Inertial Systems and Components*, December 1991, Thomas pak, George Letourneau, and Don Hunt, AGMC; *Biodegradability of Detergents and its Effects on icipal Wastewater Activated Sludge*, September 1993, Battelle; Drawings and Specifications for Water onizing and Cleaning Facilities, February 1993, AGMC; Description of Cleaning Procedures, AGMC; parison of Old and New Cleaning Methods for Fill Block, AGMC; and Description of a Cleaning tion, AGMC.

Overview of Technology and Technical Innovations

The possibility that new processes would degrade individual components or entire assemblies was a great concern at AGMC. The internal and external laboratory work done to verify the acceptability of proposed processes is examined in other sections of this report.

One procedure for testing nuclear missile guidance systems included three steps: (1) making parts ready for field testing, (2) field testing the parts for an agreed-upon length of time, and (3) tearing down the parts to verify that new processes did not have adverse effects on any part components. The tear-down operations were aided by technical representatives and reports from a number of organizations. [6] The reliability of alternatively cleaned units continues to be monitored in order to verify the field reliability of the alternative cleaning processes and the validity of the testing.

Control and Conservation of Chemical Usage

Control and conservation of solvents were major efforts at AGMC. They began with the installation of a still and other equipment to adsorb vapor from exhaust air, using an active carbon filter bed. It was found that if a filter system was used to remove chemicals from exhaust air, it was necessary to have intensive monitoring to determine at what interval recharging or replacing the filter should occur. The exhaust stream had to be monitored for a number of full maintenance cycles to insure that regular maintenance of the system had become routine.

Control and conservation enabled AGMC to determine how much chemical was used in an area and how chemical usage changed over time. This helped to reduce the consumption rate of ODCs and to prepare employees for the overall phasing-out of ODCs.

The control and conservation strategies involved intensive monitoring. A team of individuals chosen from the various production areas studied the details of every cleaning operation at the Center: the nature of the materials in the components to be cleaned, how thoroughly components were cleaned, what type of ODCs were used, how much was used each week, and how much was lost. The data that the team collected were used to determine which areas could provide the largest potential savings in ODC use. The greatest savings could be obtained by (1) replacing ODCs with water or another solvent and (2) encouraging employees to use as little ODC as possible to complete a task. [7]

[6] Further information available in:
ntification of Contamination Found Deposited on Gyroscope Ring April 1992, Battelle;
ntification of Spots Found on the Surface of the Gyroscope End-Cap 3637, June 1992, Battelle;
ute Man III Non-Continuous Engineering Support Tear Down Report for GI-T1-Bs Alternatively Cle
AGMC, March 1994, Draper Laboratory; and
uteman III ODC-Elimination Studies, July 1994, Draper Laboratory.

[7] For additional details see *A Study of Freon Vapor Loss Based on 1991 Purchases*, March 1992, fa Abraha, AGMC.

Encouraging employees to use smaller volumes of ODCs had a significant impact on the consumption rate. AGMC "used to use ozone-depleting chemicals like they were water," according to Captain Milholen. The reduction in their use was promoted in a variety of ways, including the placement of reminders over the chemical taps that dispensed chemicals in the various work areas. Monitoring strategies were key to the eventual elimination of the ODCs. They helped employees who worked with the chemicals to see that the facility was serious about phasing out the chemicals, and they provided instant feedback to the project engineers, which made use of ODCs in unauthorized ways difficult if not impossible.

A series of flow meters was placed at strategic locations around the building to measure the rate of ODC use in areas that were under study. Once an area had alternative systems in place, the ODC supply lines were shut off. If employees wanted ODCs after lines were shut off, they had to formally request them. Small containers of ODCs were supplied on request, and their usage was also monitored. The control strategy was accepted by most people, but not everyone. Most were eager to have chemicals removed from the workplace, but some still had a mind-set of reliance on ODCs. On one occasion, a flow meter next to a clean room was found to have been unplugged, and a container of ODCs was confiscated by engineering personnel after an anonymous caller advised them to look under a removable floor panel in the clean room.

Caution must be exercised in interpreting chemical-tracking data. The tracking data collected by Engineering did not always correspond to the data collected by the Environmental Office. But as the volumes of ODCs used decreased, the two tracking systems indicated smaller usage differences, and these eventually became insignificant.

The selection of a baseline for comparing measurables like volumes of ODC use is important. If an organization has several branches, it will probably want to compare the measurables of various branches. But AGMC began its ODC phase-out earlier than other facilities (military, government and industrial), and it reported its savings relative to its start date, while the measurables that were reported in the form of the measurables package used by other facilities had a later baseline. The result was that AGMC had two different savings figures. Reporting different figures is acceptable; indeed, two measurements can provide a fuller picture of actual performance. But both numbers must be reported at all times, with an explanation of why there are two values instead of one; otherwise confusion will result outside the reporting facility.

ODC-Free Refrigerants

AGMC has a large number of environmental chambers that use ODCs as a refrigerant. Many of the test chambers have been converted to ODC-free refrigerants. The ozone-depleting refrigerants have been replaced by hydrofluorocarbons (HFCs), which do no harm to the ozone layer. AGMC found that conversion to HFCs was affordable and could be done by manufacturers or skilled trades people. The details of costs, procedure, testing and specific

pieces of equipment used have been summarized in a number of reports and papers.[8]

Other Technologies

Several other solvents have been tested and applied in areas where aqueous cleaning was not successful.[9] Other areas of potential interest include:

- Removal of epoxy[10]

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[8]*Alternatives to Ozone Depleting Refrigerants in Test Equipment*, Maritime Environmental posium, October 1993, Richard Hall, Battelle and Madeleine Johnson, AGMC; *ernatives to Ozone Depleting Refrigerants in Test Equipment*, International Compressor Conference, due, July 1994, Richard Hall, Battelle and Madeleine Johnson, AGMC; and *ernatives to Ozone Depleting Chemical (ODC) Dependent Test Equipment Components*, June 1995, telle.

[9]*Experimental Evaluation of the Corrosive Potential of Flux Residue Cleaning Agents*, January 2, Battelle; *Use of Perfluorocarbons as Alternatives for Ozone-Depleting Chemicals at the Aerospace and dance Metrology Center - Some Considerations*, submitted to US EPA SNAP program, August 1993; *surement of Residues from Improved Dow Corning OS-10 Fluids*, May 1994, Battelle; and *Experiment luation of the Adhesive Degradation and Corrosion Potential of Silicon Fluids*, January 1995, telle.

- Electronic-component cooling alternatives [11]
- Advanced-technology cleaning methods [12]

AGMC also worked with three private contractors, under the DOD Small Business Innovative Research Program (SBIR), to produce and test alternative technologies: The projects are as follows:
1. Membrane Technology & Research Incorporated developed a system for vapor emission recovery. Recovery systems are in operation and are capable of recovering over 99.5% of cleaning process vapors. The system can be used to recover chlorofluorocarbon, perfluorocarbon, or methyl siloxane vapors.
2. Phasex Corporation developed a super critica l fluid system. The system uses either carbon dioxide or ethane to remove substances, like silicone based fill fluids, from components with complex geometries.
3. Entropic Systems Incorporated developed a perfluorocarbon surfactant based cleaning system. The system is completely enclosed. Features include in-line laser light blockage particle counters, with a resolution of one micron, and ultraviolet sensors for detecting fluid contamination.

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[10] *Identification of Biodegradable/Environmentally Compatible Methods for Epoxy Removal -- Pha*
August 1993, Battelle; and
ntification of Biodegradable/Environmentally Compatible Methods for Epoxy Removal -- Phase II
ruary 1995, Battelle.

[11] *Electronic Component Cooling Alternatives: Compressed Air and Liquid Nitrogen* April 1993, telle.

[12] *Advanced Technology Cleaning Methods for High Precision Cleaning of Guidance Components* tember 1993, Battelle.

Pollution Prevention Pays in Precision Cleaning

The costs and savings associated with moving away from ozone-depleting chemicals are examined in this section. Current cleaning costs are estimated at $200,000 per year for consumables. (In some cases, information was not available because of the high personnel turnover at AGMC that have resulted from reduction in forces and privatization in place, transferring operations to a contractor.)

A significant number of changes have been made at the facility in the process of gradually eliminating ODC consumption. Most of the efforts associated with these changes fall into one of the following six categories:

1. Reclamation of Solvent
Solvent reclamation efforts began in 1980. A substantial quantity of contaminated CFCs were then stored outdoors in palletized drums. Solvent reclamation was initiated as a cost-reduction initiative and in response to concerns about the Earth's ozone layer and to changes in the waste disposal regulations of the Environmental Protection Agency.

Upon start-up of the distillation unit, 79,000 gallons of ODC waste were in storage. Waste had been stored from 1978 onwards. Assuming a yield of 50% from each drum, the value of the chemical was $367,000. [13] Additional savings result from disposing of 50% fewer drums. The savings through the reclamation of waste storage and the reduction of drum disposal gave an immediate payback for the $407K cost of the still and associated equipment.

Solvent was also reclaimed by passing ODC-saturated fumehood exhaust vapors through a carbon bed. The ODCs were reclaimed by running water through the bed and distilling the water/chemical mixture. The cost of the system and its installation was $51,000 in 1981. (No data are available on the quantity of chemical recovered using this method.)

2. Tracking and Conservation
Tracking and conservation were essential elements in the ODC-elimination program. (Associated costs were flow meters and manpower. It is difficult to quantify the reduction in chemical use from this part of the program, and the effects on other parts of the program are also difficult to estimate.) Approximately six person-years were applied to the tracking and conservation program over a three-year period. Two engineers were key to these efforts, but a number of other people were also involved on an as-required basis.

Solvent was reclaimed in a number of other ways. Enclosures were placed around benchtop work areas to contain ODC vapors. Vapors were channelled into a machine which separated the ODCs from the air. If an open can of ODC was to be used, a "hat" was placed on it to condense ODC vapors, which dropped back into the container. Modifications were made to ODC delivery and collection systems to reduce the quantity of volatile ODC vapors escaping into the atmosphere.

[13] 79,000 gallons (1750 drums) x 13.16 lbs/gallon x 50% recovery (a conservative estimate) x 9/lb. (1980 price of CFC) = $366,700. At 1990 prices, the value of the chemical is $1.2 million.

3. Conversion to Aqueous Cleaning

Most processes at AGMC have been converted to aqueous cleaning. Some components require less manpower and time to clean, but others require more. (The fluctuations in volume, coupled with the structure of the accounting system, do not allow the process engineers to make accurate estimates of increases or decreases in manpower and processing time.) [14]

Expenses associated with cleaning program are as follows:

Ultrasonic Cleaner (1985)		$ 150K		
2-Ultrasonic Cleaners (1991)		98		
9-Ultrasonic Cleaners (1992)		145		
Facility costs first system (1990)		20		
Facility costs and other equipment (1991)		95		
Additional equipment		46		
Facilities (1992)				95
Facilities (1993)				371
Facilities (1994)				169
Labor (1992)		270		
Labor (1993)		351		
Labor (1994)		507		
Material (1992)			35	
Material (1993)			63	
Material (1994)			89	
Disposal (1993)			15	
Disposal (1994)			42	
Total	**$2,561K**			

It is worthwhile to note the decrease in costs as the program and technology progressed. Technological improvements, increases in competition, and increases in the number of equipment orders resulted in declining equipment costs. If the cost of the program had been based on original estimates of requirements and equipment prices, it would have been difficult to justify consideration of the new technology. But it was possible to purchase cleaners in 1992-93 at one-tenth the price of the 1985 equipment, and AGMC was able to redesign its processes so that it required only 14 cleaning centers, instead of the original estimate of 27. In addition, 12 areas shared deionized water systems with other areas, for a further savings of $60K over initial plans.

4. Use of Other Solvents

A wide range of solvents has been tested, including methyl siloxanes (OS series chemicals), perfluorocarbons (PFCs) and hydrofluoroethers (HFEs). In all cases, the costs of ODC-alternative solvents are higher, and there are no savings through their use. In some cases, however, the quantity of solvent

[14] The number of process engineers has dropped to as low as six from its regular complement of Process engineering workload has increased while the number of engineers has dropped. Supporting ODC-elimination program required that process engineers modify all product repair specifications chnical Orders). A typical product specification (Technical Order) is over one thousand pages in gth and must have every page checked to identify areas requiring modification.

purchased and disposed of has been reduced through distillation of the solvent for reuse. Solvents currently in use include:

- PF-5052
- PF-5070
- PF-5862
- OS-10
- OS-30
- Versaclean
- PF Cleaner
- EZE244
- AK-225
- N-heptane

5. Supporting Documentation and Testing
A substantial amount of testing of the new processes has been completed. In some cases, the ODC-elimination program moved forward so quickly that the test results could have been anticipated before they were received because of the development work being carried on concurrently. But if the development program had been halted by an unresolvable technical issue, the laboratory work would have provided vital assistance in the search for solutions.

One question that arises at this point is whether laboratory work should be commissioned only when a problem occurs and not in anticipation of possible problems. Research conducted only on an as-required basis would have reduced expenditures on outside laboratories, but it would also have extended the time for implementation of the changes.

Moreover, it is highly questionable whether AGMC would have been allowed to make major process modifications to critical parts of the guidance systems of aircraft, nuclear missiles and submarines without independent verification of the viability of the new processes. Outside testing gave scientific grounding for all the processes that were recommended and implemented.

Substantial delays would have occurred if laboratory testing had to be specified, budgeted, and contracted out as the project proceeded. Delays could have critically damaged the program. If the program had ceased to move forward, personnel at the Center might have lost their confidence in the viability of the alternate technologies.

Expenses associated with studies and research were as follows:

Pollution Prevention Pays in Precision Cleaning

Corrosion Study	$	40K
Alternate Cleaning Technology Study	200	
Cleaning Effectiveness Study	150	
Detergent Biodegradability Study	137	
Biodegradability Epoxy Removal Study	71	
Detergent Metal Compatibility Study	271	
Adhesive Degradation Study	200	
Silicon Fluid Study		200
Testing conducted through blanket agreemen		235
Total	**$1,504K**	

6. Alternative Technologies

Additional technologies were developed to eliminate the need for either cleaning or non-cleaning uses of ODCs. Alternative cleaning methods include super-critical cleaning and alcohol cleaning. These were developed as back-ups in case other parts of the elimination program failed. AGMC has cleaned samples for organizations considering these technologies, and technical advice and equipment for trial use are available to other sites.

ODCs are also used as refrigerants and for benchtop thermal testing of electronic components. Environmental chambers have been modified to use HFCs, but there is no financial advantage to this process. It is necessary, however, since the original refrigerant was an ODC. Benchtop testing of electronics involves applying compressed CFCs to a component to cool it. Nitrogen and carbon dioxide have also been used at AGMC; both are inexpensive and widely available.

The reductions in the use and cost of ozone-depleting solvents are shown in the following tables.

Year	Reclaimed (*1,000 lbs)	Purchased (*1,000 lbs)	Cost	Cost Avoidance Comparison	
				without distillation	versus 1985 baseline
1985	2165	700	$740,000	$950,000	$0
1986	2201	700	745,000	967,000	(5,000)
1987	1866	595	633,000	819,000	107,000
1988	1416	665	606,000	622,000	134,000
1989	695	450	370,000	675,550	370,000
1990	555	421	1,031,000	1,165,000	(291,000)
1991	519	314	785,000	1,089,000	(45,000)
1992	322	290	788,000	773,000	(48,000)
1993	137	199	723,000	463,000	17,000
1994	93	77	286,000	314,000	454,000

Table 1: Use and Purchase of Chlorofluorocarbons

Annual expenditure on chlorofluorocarbons changed between 1985 and 1994 for five reasons: (1) reductions in the purchase of virgin material due to use of material reclaimed by distillation, (2) increases in the cost of chlorofluorocarbons, (3) fluctuations in solvent requirements due to changes in workload, (4) reduction in quantity used due to conservation, and (5) reduction in use as a result of implementation of ODC-free cleaning technologies. The cost avoidance that can be contributed to solvent reclamation through distillation is shown in the column *without distillation*. The fluctuation in chlorofluorocarbon expenditures, compared to 1985, is shown in the column *versus 1985 baseline*. Prior to the operation of the still, purchases were in the magnitude of 1,200,000 lbs. of CFC-113 annually. CFC-113 cost $.59/lb. in 1980. The cost of distillation was calculated by AGMC as $.15/lb. Imposition of taxes on ODCs in general resulted in substantial increases in unit prices for CFCs. The costs of CFC-113 were $2.25/lb. in 1990 and 1991, $2.55/lb. in 1992, and $3.53/lb. in 1993 and 1994. Usage in 1995 is small enough that no further purchases will be required before ODCs are completely phased out from the facility. (Note the drastic decline in usage in 1994.)

Quarter/Year	CFC-113 (number of uses)	Trichloroethane (number of uses)
1992-Baseline	740	367
1993/1Q	725	363
1993/2Q	710	356
1993/3Q	385	165
1993/4Q	385	165
1994/1Q	157	51
1994/2Q	116	32
1994/3Q	112	28
1994/4Q	52	Data Unavailable
1995/1Q	46	Data Unavailable

Table 2: Change in Number of Production Uses

Year	Quantity of Work (Labor Hours)
1989	1.9 Million
1990	1.8 Million
1991	1.5 Million
1992	1.3 Million
1993	1.0 Million
1994	0.9 Million
1995	0.7 Million

Table 3: AGMC Workload

It is not possible to isolate the effect of reduction in workload on ODC consumption, because the internal accounts distribute ODC usage as a function of direct labor.

ODC Elimination at AGMC

AGMC staff first recognized in 1975 that certain chemicals used in large quantities at the facility might pose a threat to the ozone layer. No immediate action was taken, but many organizations did not even see ODCs as a potential problem until over a decade later.

The first steps to reduce consumption of ozone-depleting chemicals were taken in 1980, when AGMC installed two distillation units to retrieve chlorofluorocarbons and methyl chloroform from its cleaning processes. The stills reduced the amounts of ODCs that had to be purchased and the amount of waste that required disposal. (No information is available on the cost avoidance in hazardous waste disposal.) Not only were the ODCs from the cleaning processes distilled for reuse, but approximately 1,750 drums of waste stored outdoors were also reprocessed. The overall result was a significant reduction in purchases, although usage rates remained the same at that time.

In 1981 it was noted that responsibility for the chemicals was shared by a number of groups in the organization -- e.g., the Environmental, Purchasing, Civil Engineering, and Maintenance Directorates. A proposal was made and accepted that the use of ODCs should be tracked by one group. Don Hunt volunteered his Quality and Reliability Engineering section for this task because it fit the section's mission of improving the quality and reliability of the repair of guidance systems.

The base commander, a chemical engineer, also took an interest in ODC reduction. In 1985 he supported the purchase of an ultrasonic aqueous cleaning system and a carbon adsorption unit. Initial experimentation with aqueous cleaning was not very promising. With the departure of the commander, management interest in these two projects waned. But two years later, Mr. Hunt, now the deputy chief of the Engineering Division, gradually restarted the investigation into aqueous cleaning.

The revived aqueous cleaning program operated on a shoestring budget. Equipment to supplement the aqueous cleaner was "borrowed" from areas across the center. Gene Ott explains:" If you go out and you find it [needed equipment] and you say, 'Do you need that thing?' chances are they'd say No. But if you just go out with a blanket statement, 'If you have excess equipment, tell us,' they won't do it. So you have to go out and find it, and then they will in most cases let you have it."

Early attempts at cleaning with water were focused on parts in two categories: (1) parts that were originally specified to be cleaned with water but had been switched to ODCs, and (2) parts that were considered to be robust -- for example, ball bearings.

Work began on scrap parts. Every time an experiment failed to produce clean, undamaged parts, variables would be adjusted and a new experiment would begin. The main variables were detergent type, concentration, temperature, soak time, rinse time and drying time. The detergent supplier provided valuable technical assistance and advice at this stage of the project. Eventually successes were obtained, and by 1989 aqueous processes had been established for bearings and for G200 and G280 gyros.

During this period, management and administrative activity started. The base commander agreed that the 1987 Montreal Protocol (setting firm dates for the elimination of ODC production) showed that "there is a need to eliminate ODCs." The Finance department became involved in 1989 to determine the whats, whens, wheres and hows of obtaining resources for expanding on the initial successes of the aqueous cleaning program. What had been a pet project of some of the engineers at AGMC was becoming a technical strategy for the entire base.

In 1990 three additional engineers were assigned to the project: Captain George Letourneau, Captain Vernon Milholen and Tesfa Abraha. Captain Letourneau created a database to characterize the over 1,100 component combinations of cleaning processes. The database that his team created identified (1) the cleaning solvents used, (2) the quantity of solvents used, (3) component materials, and (4) processing locations.

At this, Captain Milholen and Mr. Abraha spent weeks on top of clean-room roofs tracing the ODC distribution system plumbing to determine how chemicals were moved to and retrieved from the various usage points. This information was vital for tracking, controlling, isolating, and eliminating the flow of chemicals as the ODCs were phased out from one area after another over the next few years.

By 1990 work had proceeded far enough that conference papers could be delivered on technological advances in use at AGMC. Environmental Protection Agency interest in the project led to an invitation to Mr. Hunt to present a paper on precision cleaning at a conference in Singapore in September 1990. There he was asked to represent the Air Force on the United Nations Environmental Program Technical Committee on Alternate Solvents for Ozone-Depleting Chemicals. The Center now had high visibility as a technology leader not only in the Air Force but in the entire Department of Defense.

The following November, AGMC customers were advised of the intention to phase out ODCs and asked to consider adopting blanket agreements to accomplish it. Initial agreements were established quickly with client organizations that provided a small percentage of AGMC's work load, but additional time was required to obtain agreements with aircraft and missile customers. The challenge was to secure agreements that satisfied customers, product engineers in the Missile division at AGMC, and the alternative process development team at AGMC that the field reliability of the guidance systems would not be adversely affected by the changes. There was a great deal of discussion and negotiation, at times quite heated. One off-site meeting of Center personnel almost became a brawl: "They had to come out and drag us off the sidewalk, because we were fighting", according to a process engineer. In an initial briefing at a customers site, Captain Campbell says, "There was a lot of animosity. I mean, I got nailed the first time I went out there -- I mean, literally nailed!" Additional discussions created better understanding of the concerns of all the parties, and mutually acceptable agreements were finally worked out. Due to financial cuts within the Department of Defence, AGMC became the "only game in town" for researching and testing ODC-alternative cleaning methods. Other organizations could have developed alternative processes, but neither as quickly nor as inexpensively as AGMC.

At the beginning of 1991, the groundwork for the program had been set. Negotiations for blanket agreement had begun with all customers. Some components were undergoing aqueous cleaning at AGMC, and submissions had been made to support research projects. Captain Bob Campbell joined the base in January, where he was assigned to new process development.

Environmental problems often require skill sets and backgrounds different from those commonly found at many facilities. Organizations working to eliminate environmental threats are often faced with the challenge of asking their technical specialists to address problems that they have not been trained for. Captain Campbell realized that he would have to master technical areas which were outside the core expertise of most of the team members, mechanical and electrical engineers. The AGMC project raised complex issues in materials science, metallurgy and chemistry. Tesfa Abraha, a chemical engineer, filled many of the knowledge gaps relating to chemistry.

AGMC now faced the challenge of moving to cleaning all the components with the new processes. Parts that had not yet been shifted were orders of magnitude more difficult to clean than the ones already done.

The initial problems that faced the team were water quality and transport of sensitive components to a central cleaning center. It was discovered that the quality of water available on the base was not satisfactory for cleaning. An upgrade of the entire DI (deionized) water system was required. It was then discovered that parts treated in one location could not be guaranteed to be clean when they were transported back to their primary work area. Cleaning centers might have to be installed in many work areas before field-ready parts could be cleaned. As many as 27 cleaning centers would be required. Some cleaning centers were modified several times before an acceptable configuration was obtained.

The first half of 1991 witnessed the arrival of the senior management team that oversaw the program till its finish. Colonel Joseph Renaud became the commander of Newark AFB in May. Tony Skufca took over the Maintenance directorate in August. Mr. Hunt spoke to these two key managers about the importance of ODC elimination and the great strides that AGMC had made in this area under his stewardship. The vision of the Maintenance directorate was released in October in *The Directorate of Maintenance Plan for Eliminating Ozone-Depleting Solvents from Its Industrial Processes* External awareness of the progress of AGMC increased as a result of Mr. Hunt's participation on the UNEP Solvents Technical Options Committee and his presentation of technical papers at a variety of conferences.

At the beginning of 1992, pollution prevention funds became available from the Air Force.
The financial planning phase was completed by the Finance department, and as Finance's involvement waned, Purchasing's participation increased. Purchasing acquired a wide range and large volume of equipment that was required for the ODC-elimination program, and did so quickly.

In February, President Bush's press secretary released a statement which expressed the intent of the administration to accelerate phase-out of ozone-depleting solvents. One month later, AGMC released its policy *The Directorate*

of Maintenance Plan for Eliminating Ozone-Depleting Solvents from Its Industrial Processes. Within a few months, the missile customers agreed to allow ten GIT-1B gyroscopes rebuilt employing aqueous cleaning processes for field testing. The Ogden Air Logistics Center also agreed to provide a five-day turn-around for every AFTO22 (process change request) generated to document changes to cleaning processes. Two months later, the aircraft customers signed an agreement with AGMC making approval of AFTO22s automatic unless a customer disapproved the AFTO22 within three days.

In May there was a reduction in forces (RIF) at AGMC, accompanied by a number of retirements and a modification of the base's reporting structure. Mr. Hunt, the driving force behind the ODC-elimination program, was promoted to Chief Scientist, a position that Colonel Renaud said "makes use of his talents." Jerry Anderson was moved from the position of Chief Scientist to become the Director of Engineering. The direct influence of Mr. Hunt on the project engineers gradually declined as he focused on his new job responsibilities. Mr. Hunt was assured by the supervisor of the Engineering/Methods laboratory branch that the program would continue even without direction from him, but the change caused some disruptions. They ceased when Don Durbin, supervisor of the Engineering/Methods laboratory branch, was placed in charge of the area. Mr. Durbin's style is the *manager as a coach.* This suited the aggressive and technically sophisticated project engineers better than the more traditional management style of his predecessor.

In mid-1992 "things really started to happen." A management steering committee composed of all key directors from across the organization was now in place. Each month a status report was presented to the steering committee. However, delays or other problems that occurred did not have to wait for resolution until the monthly meeting. Project engineers were advised to take problems immediately to the director level. If issues could not be solved at the director level, the instructions were to take them to Colonel Renaud, the base commander. He promised to stop whatever he was doing and resolve the issue immediately. The system worked well and Colonel Renaud was never asked to settle an issue.

Insuring that a task was completed quickly, without frequent intervention, required a way to indicate that the task was important. Placing a "Rush" or "Urgent" label on a work request was not satisfactory, since in-baskets were always piled high with "Urgent" work requests. Historically, an urgent request could be expedited by "walking it through the system," but the number of work orders generated by the new program made this approach impossible. Colonel Renaud proposed the use of an "Ozone" stamp. A document with "Ozone" stamped on it in red ink was to be taken care of first. When an "Ozone"-stamped document arrived in any area (Finance, Contracting, Logistics, Civil Engineering), work on all other projects immediately ceased. "Ozone"-stamped documents were handed to individuals personally; they never sat in an in-basket. To minimize disruption, departments assigned one individual to handle all "Ozone" tasks. If there were many "Ozone" tasks at a specific time, the individual went to a supervisor and obtained instructions, and sometimes additional manpower was assigned to an area. On occasion, there were too many requests for a department to handle, but that problem was quickly moved up the management chain to be resolved. Resolution of problems was always fast, because everyone knew the Center's goal, and they all wanted AGMC to succeed.

From the end of 1992 to the beginning of 1994, Madeleine Johnson managed the conversion of many of the environmental chambers to the non-ozone-depleting refrigerant HFC. This conversion project was on the cutting edge of technology. To encourage diffusion of this technology across industry, manufacturers were invited to participate where possible.

During this period, results from external research started to arrive, but the development team's enthusiasm and hard work consistently put them ahead of the laboratory research results.

The names of Captain Bob Campbell and Captain Vernon Milholen became closely associated with the ODC-elimination program, in the minds of many center personnel.[15] In fact, Captain Campbell was renamed "Captain Ozone." All team members put in an impressive effort. It was not unusual for individuals to work extra hours at the Center. For example, Chuck Davis often stayed on through afternoon and evening shifts when people had questions: "You have to go to that shift to straighten [problems] out for them...[A person] worked on third shift, and he wanted the answer. So you did also have to go to the off-shifts."

In June 1992 the first non ODC cleaned GIT-1B was installed on a nuclear missile. The original plan was to do a "tear-down" on it if it failed, to determine what effects, if any, the aqueous cleaning procedures had on it. It was assumed that failure would occur within a six-month time frame. Much to the surprise of many technical people who were sceptical of the use of aqueous cleaning, the gyroscope did not fail. But surprise gave way to curiosity, and in May of 1993, the first unit was retrieved from the field for a tear-down. Rockwell and Charles Stark Draper Laboratories both participated. Each component in the GIT1B gyroscope was carefully examined. Degradation of some components was found, but none associated with the aqueous cleaning.[16]

In February of 1993, Civil Engineering issued drawings and specifications for deionized water systems and cleaning centers. This was followed by a flurry of activities in Civil Engineering as changes were made to install aqueous cleaning centers in all affected areas. Throughout this period, Civil Engineering resources were under enormous pressure. The aggressive targets set by the program led Captain Campbell to request major changes to several locations at the same time. Captain Campbell was in such a rush that if there was a delay, he would do things himself and even spend his own money on them.

[15]Although Captain Milholen and Captain Campbell were not in charge of the program, their ivities and personalities brought them into substantial base-wide association with the program. In erview after interview, their involvement with the project was noted.

[16]One engineer has described the consternation he felt when black discoloration of the flex leads the baffle plates showed up on the first instrument that was torn down. But examination of baffle tes cleaned by regular processes revealed similar contamination. The aqueous process did not cause contamination. The explanation for the black contamination was the flex leads, which were three cent beryllium copper. Although it is not dramatically susceptible to corrosive effects, chlorides, fides, and phosphates all have a detrimental effect on it: "From chromatographs [we knew] that re were no chlorine ions in the water and there were no chlorine ions in the detergents. So where e the chlorides coming from? The fill fluid."

According to Rick McDonald, AGMC pipe fitter, "He went down to the local hardware store. The tool he bought was not really sturdy enough.... It broke within a few hours, and he went down and got a better one...made the whole job that much faster."

Process development was conducted in the clean rooms. The technicians in charge of regular production worked with the ODC-elimination project staff to find suitable alternative processes. Their involvement was one reason for cooperation by all the employees. Another was that the alternative cleaning processes worked well, and a third, that strong support was given to the project by engineers and technicians. Technicians were concerned about the environment, and they considered the new processes to be better for their health (they no longer had complaints about the smell of the cleaning solvents). In addition, trainers convinced work-area opinion leaders of the viability of the new processes before they were put in place.

The second briefing to customers of the Missile division occurred in March. This briefing was very different from the first one, at which Captain Campbell described himself as "getting nailed." The briefing went very smoothly, beyond the original half hour scheduled for it and continuing for about two hours. The hard work by the ODC-elimination team and the substantial background research conducted by Captain Campbell paid off. As a result of the successful tear-down and this briefing, customers of the Missile division joined the aqueous cleaning bandwagon. By September all of the GIT-1Bs were being cleaned with alternative processes, and work was under way on developing processes for a range of other missile products.

On March 11 1993, the local newspaper carried an announcement that Newark Air Force Base had been put on the closure list. Many people reacted with disbelief: "When we first found out we were closing, we couldn't believe it -- because we thought we were so unique. And I remember when I first started here, I saw training films, and they were talking about reduction in force and closure, and even the person [who] was running the film stood up and said, 'Don't even listen to that. That'll never happen to us."' The ODC-elimination program later suffered from shortages of process engineers in the Aircraft and Missile divisions, but the general level of support for the program did not waver. The attitude was "Let's show them how stupid they were for closing us."

Throughout 1993, consumption was reduced, cleaning centers were constructed, and suitable alternative cleaning processes were established. The major difficulty the program faced at this time was the completion of AFTO22 requests.[17] A write-up on a new process developed by the project team and the technicians who cleaned and repaired guidance systems was prepared by a project engineer and handed to the process engineers, who prepared the AFTO22s. Normally the preparation of a process change of this type could take up to six months to complete. Until the AFTO22 was approved, the new ODC-free process could not be implemented. But a series of discussions were held that resulted in agreement on a one-month turnaround for AFTO22 modifications. The

[17]The AFTO22 request is a notice asking for changes to the existing process documents. An AFTO22 issued prior to any process changes being instituted.

one-month turnaround required compromises that some process engineers are still uncomfortable with. For instance, the level of detail in a process document had to be greatly reduced. Some people feel that this is a tremendous sacrifice, since a process document serves as a training manual on how a task is to be completed. Other people say that a manual is used only for initial training, which employees can obtain from interaction with senior employees. Customers had trouble approving AFTO22s within the short time frame. On-site meetings of process engineers and customers were held to iron out difficulties and help the customers better understand what was happening at the Center.

In 1994 many parts of the program started to wind down. By March, the management steering group was no longer necessary: on 39 completed workloads, only two minor problems remained. At this stage, support for the program was as natural as a reflex action for most Center employees. Purchasing personnel were one of several groups that received awards from the Commander for their contributions in support of the ODS program. [18]

Over time, the project team shrank in size. Mr. Ott and Ms. Johnson were given new responsibilities. Captain Letourneau retired. Mr. Abraha, Captain Milholen and Captain Campbell (now retired from the military) remained on the project. All that was left to do was to tie up loose ends and provide technical information to interested groups in government and industry. In May, representatives of French industry visited the Center to learn more about the technologies that had been developed.

[18] Awards of various types were given to support personnel throughout the program.

Chronology of Events in the Phase-out of Ozone-Depleting Chemicals at AGMC, Newark

1975

- First mention, in internal documents, of adverse effects of CFCs on ozone layer.

1980

- CFC waste tanks outside building.
- December - Still for reclaiming ODC is installed and activated.

1983

- Installation of carbon bed adsorption unit to remove CFC vapors from exhaust air .

1985

- First aqueous cleaning station acquired (changes in personnel and priorities resulted in no experimentation with new equipment).
- Freon use at 2,000,000 pounds per year.

1987

- Work on aqueous processes started in Quality and Reliability Engineering branch.

1988

- Meeting in base commander's office confirms need to eliminate ODCs.
- July - "The Cyl-sonic Cleaner: Aqueous Ultrasonic Cleaning Using Biodegradable Detergents" prepared by Kenneth Patterson and Don Hunt.

1989

- Finance department involvement begins.
- Gene Ott joins project (alternative proces s development).
- Aqueous processes established for bearings, G200 and G280 gyros.

1990

- Tesfa Abraha joins project (conservation and tracking).

- Adjustments to maintenance system of carbon bed adsorption unit to obtain better performance.
- Captain George Letourneau joins project (administration and collection of use information).
- January - "Aqueous Cleaning of Instrumentation Bearing Assemblies" prepared by Gene Ott.
- July - "GIT-1B and TG (Beryllium) End Housing Aqueous Cleaning Project Summary to Date" prepared by Thomas Ciupak.
- August - "Aquasonic Cleaning Project" presented by Mike Then of Wright Patterson to AGMC.
- September - "A US Air Force Repair Center's Policy and Progress in Eliminating CFCs" presented by Don Hunt to the U.S./Singapore Conference on Alternatives and Substitutes to CFC Solvents, Singapore.
- October - Request for information on CFC reduction from General Viccelio (Deputy Chief of Staff Logistics and Engineering) to Don Hunt.
- November - Initial contacts with missile customers seeking agreement to change cleaning process to ODC alternatives.
- 4th Q - Collection of data on all ODC uses.

1991

- Submission of research projects to funding office.
- Actions taken to improve quality of de-ionized water.
- Two technicians join ODC Process Development Team.
- Detergent compatibility studies conducted.
- Deputy Chief Don Hunt named to UNEP Solvents Committee.
- 1st Q - Work on GIT-1B commences.
- January - Laboratory work conducted on scrap parts.
- January - Captain Bob Campbell joins project (new process development).

- March - "Implementing Alternatives to Ozone-Depleting Solvents - Some Considerations" presented by Don Hunt to Military Volatile Organic Compound (VOC) Workshop.

- May - Colonel Joseph Renaud arrives at base (Center Commander).

- June - Work at AGMC is used as a case study of "ozone-friendly" precision cleaning in EPA publication *Eliminating CFC-113 and Methyl Chloroform in Precision Cleaning.*

- July - "Precision Bearings Cleaned at AGMC" prepared by Ray Vargas.

- August - Submission by Don Hunt to AGMC regarding European progress on ODC phase-out.

- August - Tony Skufca arrives at base (director of maintenance), discusses ODC-elimination with Don Hunt.

- September - Submission by Don Hunt to AGMC regarding phase-out of CFC-113 and MCF at AGMC; UNEP Asia Trip Report.

- 3rd Q - Discussions between Colonel Renaud and Don Hunt regarding ODC elimination.

- October - "The Directorate of Maintenance Plan for Eliminating Ozone-Depleting Solvents from Its Industrial Processes" prepared by AGMC.

- November - "Aqueous Cleaning for Precision Bearings and Beryllium" prepared by Don Hunt, Gene Ott, Thomas Ciupak and Ray Vargas.

- December - "Aqueous Alternatives to CFC-113 and MCF for Precision Cleaning of Inertial Systems and Components" prepared by Thomas Ciupak, Captain George Letourneau and Don Hunt.

1992

- Finance involvement tails off.

- Management elevates ODC phase-out to p riority for the Center.

- Madeleine Johnson joins project (various responsibilities).

- Intense activity in Purchasing.

- Pollution prevention funds acquired for testing and research.

- Steering committee addresses issues associated with the ODC-elimination program.

- Statement of intent by AGMC to phaseout ODCs by December 1993.

- January - "Experimental Evaluation of the Corrosive Potential of Flux Residue Cleaning Agents" submitted by Battelle to AGMC.

- February - "Eliminating Ozone Dep leting Solvents in an Industrial Activity" presented by Don Hunt to Joint Logistics Commanders Meeting, Brooks Air Force Base, TX.

- February - News release on accelerated phase-out of ozone-depleting solvents by White House press secretary.

- March - "A Study of Freon Vapor Loss Based on 1991 Purchases" prepared by Tesfa Abraha.

- March - "Draft Action Plan to Implement the Proposed AGMC Policy for Eliminating Ozone-Depleting Solvents from Maintenance Industrial Processes" prepared by AGMC.

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- January -ODC elimination open house "work force recognition program."

- February - Retirement of Don Hunt.

- October - Base privatized in place (projected).

Chronology of Technical Events in the Phase-Out of Ozone-Depleting Chemicals at AGMC, Newark

1975

- First mention, in internal documents, of adverse effects of CFC on ozone layer.

1980

- December - Still for reclaiming ODC is placed on-line.

1983

- Installation of carbon bed adsorption unit to remove CFC vapors from exhaust air.

1985

- First aqueous cleaning station acquired (changes in personnel and priorities resulted in no

  experimentation with new equipment).

1987

- Work on aqueous processes started in Quality and Reliability Engineering Branch.

1988

- July - "The Cyl-sonic Cleaner: Aqueous Ultrasonic Cleaning Using Biodegradable Detergents" prepared by Kenneth Patterson and Don Hunt.

1989

- Aqueous processes established for bearings, G200 and G280 Gyros.

1990

- Adjustments to maintenance system of carbon bed adsorption unit to obtain better performance.

- January - "Aqueous Cleaning of Instrumentation Bearing Assemblies" prepar ed by Gene Ott.

- July - "GIT-1B and TG (Beryllium) End Housing Aqueous Cleaning Project Summary to Date" prepared by Thomas Ciupak.

- August - "Aquasonic Cleaning Project" presented by Mike Then of Wright Patterson to AGMC.

- 4th Q - Collection of data on all ODC uses.

1991

- Actions taken to improve quality of de-ionized water.

- Detergent capability studies conducted.

- 1st Q - Work on GIT-1B commences.

- January - Laboratory work conducted on scrap parts.

- March - "Implementing Altern atives to Ozone Depleting Solvents - Some Considerations" presented by Don Hunt to Military Volatile Organic Compound (VOC) Workshop.

- July - "Precision Bearings Cleaned at AGMC" prepared by Ray Vargas.

- November - "Aqueous Cleaning for Precision Bearings and Beryllium" prepared by Don Hunt, Gene Ott, Thomas Ciupak and Ray Vargas.

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Chronology of Administrative Events in the Phase-Out of Ozone-Depleting Chemicals at AGMC, Newark

1975

- First mention, in internal documents, of adverse effects of CFC on ozone layer.

1980

- CFC waste tanks outside building.

1985

- Freon use at 2,000,000 pounds per year.

1988

- Meeting in Base Commander's office confirms need to eliminate ODCs.

- July - "The Cyl-sonic Cleaner: Aqueous Ultrasonic Cleaning Using Biodegradable Detergents" prepared by Kenneth Patterson and Don Hunt.

1989

- Finance department involvement begins.

- Gene Ott joins project (alternative process development).

1990

- Tesfa Abraha joins project (conservation and tracking).

- Captain Letourneau joins project (administrative and collection of use information).

- January - "Aqueous Cleaning of Instrumentation Bearing Assemblies" prepared by Gene Ott.

- July - "GIT-1B and TG (Beryllium) End Housing Aqueous Cleaning Project Summary to Date" prepared by Thomas Ciupak.

- August - "Aquasonic Cleaning Project" pres ented by Mike Then of Wright Patterson to AGMC.

- September - "A US Air Force Repair Center's Policy and Progress in Eliminating CFCs" presented by Don Hunt to the U.S./Singapore Conference on Alternatives and Substitutes to CFC Solvents, Singapore.

- October - Request for information on CFC reduction from General Viccelio (Deputy Chief of Staff Logistics and Engineering) to Don Hunt.

- November - Initial contacts with missile customers seeking agreement to change cleaning process to ODC alternatives.

1991

- Submission of Research Projects to funding office.
- Actions taken to improve quality of de-ionized water.
- Two technicians join ODC Process Development Team.
- Deputy Chief Don Hunt named to UNEP Solvents Committee.
- January - Captain Bob Campbell joins project (new process development).
- March - "Implementing Alternatives to Ozone Depleting Solvents - Some Considerations" presented by Don Hunt to Military volatile organic compound (VOC) Workshop.
- May - Colonel Joseph Renaud arrives at base (Center Commander).
- June - work at AGMC is used as a case study of "ozone friendly" precision cleaning in EPA publication *Eliminating CFC-113 and Methyl Chloroform in Precision Cleaning.*
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- August - Submission by Don Hunt to AGMC regarding European progress on ODC phase out.
- August - Tony Skufca arrives at base (Director of Maintenance), discusses ODC-elimination with Don Hunt.
- September - Submission by Don Hunt to AGMC regarding Phase-out of CFC-113 and MCF at AGMC; UNEP Asia Trip Report.
- 3rd Q - Discussions between Col. Renaud and Don Hunt regarding ODC elimination.
- October - "The Directorate of Maintenance Plan for Eliminating Ozone Depleting Solvents from its Industrial Processes" prepared by AGMC.
- November - "Aqueous Cleaning for Precision Bearings and Beryllium" prepared by Don Hunt, Gene Ott, Thomas Ciupak and Ray Vargas.
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1992

- Finance involvement tails off.

- Management elevates ODC phase-out to priority for the Center.

- Madeleine Johnson joins project (various responsibilities).

- Intense activity in Purchasing.

- PP funds acquired for testing and research.

- Steering committee addresses issues associated with the ODC-elimination program.

- Statement of intent by AGMC to phaseout ODCs by December 199 3.

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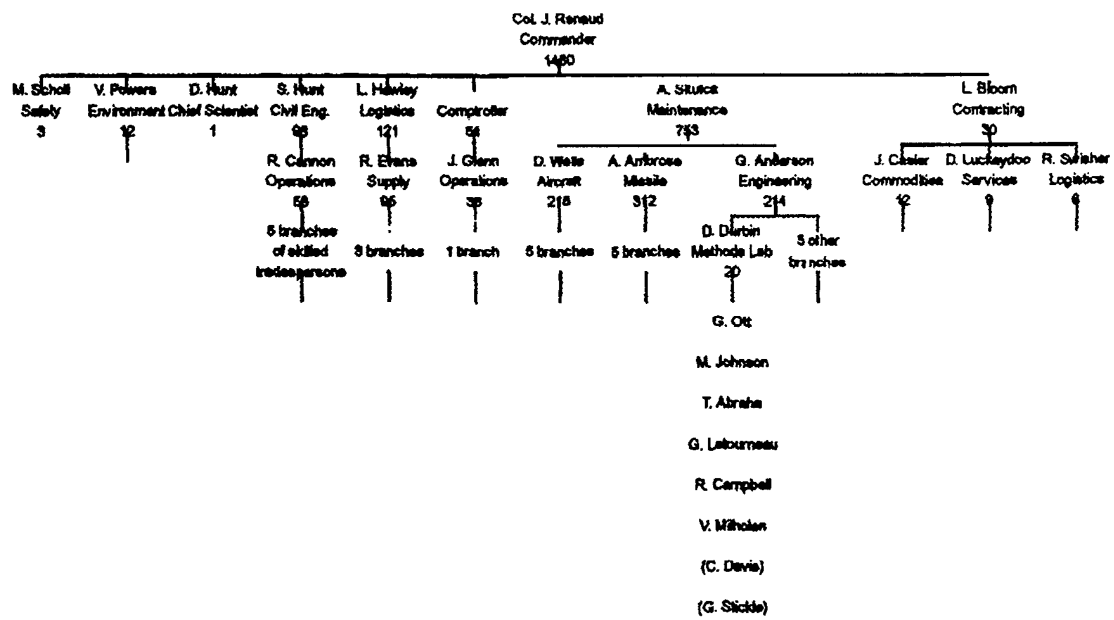
Figure 2: Organization Chart Depicting All Personnel with Significant Involvement in ODC-Elimination Program (based on organizational structure as of July 1995)



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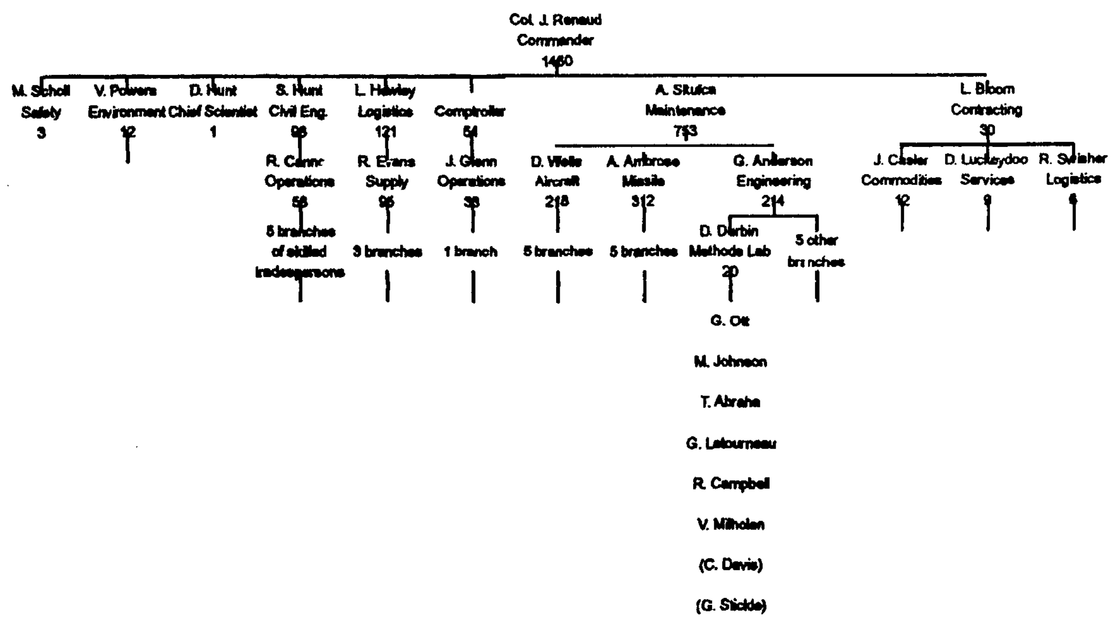

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Organizational Structure

The ODC-elimination program at AGMC started about 15 years ago. During this time there has been a substantial drop in the number of people working at Newark AFB and corresponding structural reorganizations. The organizational structure that is discussed in this section was in place from 1992 to 1995, following the reduction in forces (RIF) in 1991-92 . The only change of significance to the program was the selection of Don Hunt as chief scientist. Before RIF he was the assistant deputy director of engineering, above Don Durbin and below Jerry Anderson. He had considerable engineering resources under his direct control. As the chief scientist he could only make suggestions to project engineers and had no staff reporting to him.

Figure 1 shows a simplification of the management structure associated with the elimination of ODCs. The base commander and the directors, who were to provide support functions, formed a steering committee that met on a monthly basis for status reports. Status reports were initially made by the ODC-elimination project engineers, but towards the end of the program, process engineers from the Aircraft and Missile divisions gave status updates to the steering committee. The ODC-elimination project engineers were aware of the base's objectives and made many of the decisions on how best to meet these objectives.

Resource conflicts, were quickly elevated to the relevant steering committee members. If they could not be settled there, the base commander was to be informed immediately. None rose that high over the duration of the program.

Figure 2 presents a more detailed organizational chart showing each individual's area (as of July 1, 1995) and the number of employees or branches working in the area.

The steering committee identified in figure 1 includes individuals from the top two management levels. ODC-elimination project engineers are listed under Mr. Durbin. (Note that Mr. Durbin has 20 employees reporting to him; ODC-elimination is not his only responsibility.)

Organizational Structure

The organizational chart in figure 2 is correct in terms of personnel deployment. But two trainers were temporarily loaned to the project engineers by the Aircraft and Missile divisions, and ODC-elimination tasks received top priority. These tasks were generated by ODC-elimination project engineers. The result was a matrix organization in which project engineers issued tasks that took priority over everything else as long as the requests were reasonable. Lines of command extended from the project engineers to every branch and department of the organization.

Creating an Environment Which Does Not Prevent Innovation

The first step toward encouraging innovation in the workplace is to create an environment which does not prevent or stifle innovation. As Don Hunt, chief scientist, points out. "Innovations are very fragile, they need to be nurtured." Important factors in creating an environment that does not discourage innovation include:

- Management support of innovation

- Identifying a vision (goals) at the top of the organization, leaving details to people closer to the actual tasks

- Minimizing red tape

- Placing people in positions that match their personalities and abilities, and encouraging people to be themselves.

Management Support

A pro-innovation environment can be maintained only with broad management support at the top and middle levels of an organization.

Consistent expressions of support and reinforcing actions from top management encourage innovation. The base commander, at AGMC, Colonel Renaud said, "If there is a problem at any time that cannot be resolved at a lower level, interrupt me." According to Colonel Renaud, "It is not enough to have a goal; you must constantly reinforce the communication." He reinforced it with action dedicating time on an on-going basis to participate in meetings associated with the ODC program: "I was demonstrating that I was interested."

In many organizations, middle management perceives its task as only managing the existing organization, an attitude that may lead it to oppose innovation which is disruptive of routine. If an organization has consistent long-term top management support for innovation, support at lower management levels will become part of the management culture.

The frequent management changes that are a feature of military, government and other large organizations can reduce their receptivity to innovation. If a pro-innovation management is replaced with a more conservative management, innovative activities may rapidly terminate. If a status-quo management is replaced with a pro-innovation management, time is required before changes in guiding principles are understood and acted upon. In an organization where management changes frequently, innovation can become part of the routine if there is a series of pro-innovation managers, but, they may modify a project's focus. The change in base commanders in 1985 brought a lull in activity in the newly started aqueous cleaning program. After Colonel Renaud's arrival in 1991, the base's management team remained stable throughout the rest of the program, and the project proceeded smoothly.

point of contact for the program-related work. An individual who required assistance to complete the work quickly could inform the supervisor. If that supervisor was not able to provide assistance, a request could be directed to the next higher supervisor. This process could continue up to the level of the base commander, but in fact nothing had to go that high.

It was understood that if an ODC-elimination task was stalled or sat in an in-basket, the reason would have to be explained directly to the base commander. When Colonel Renaud took actions that confirmed his continued commitment, he too became subordinate to the ODC-elimination program.

If, in this sense, the ODC-elimination program was running the base, who was running the program? A small number of "Ozone" stamps were issued to various individuals who handled most of the ODC-elimination program tasks. Program tasks issued by one of these areas had a red prominent "Ozone" label stamped on them. Tasks usually originated from the project engineers working on the program. To some people it appeared that these individuals had wide-ranging powers, but although they were able to interrupt work on other tasks and assign people to tasks, they only assigned tasks that were essential to the program. At one point requests that were considered unreasonable were made to a Civil Engineering tradesperson, who advised a supervisor, who in turn immediately elevated the problem to Lieutenant Colonel Stan Hunt, the director of Civil Engineering. Lt. Col. Hunt met with the people involved, and within a few minutes, the tasks were redesigned in a more manageable form. Occasional incidents like this also suggest that the ODC-elimination program was in charge, not any particular individual.

If an organization has one, clear-cut goal which needs to be the top priority (like the development and implementation of a new technology), the system used at AGMC is recommended. Everyone in the organization needs to <u>see</u> that the organization's head is completely committed to meeting the goal. Consistent, on-going actions indicate clearly that it is the top priority. Each task is handed directly to the individual who is supposed to carry it out. The system relies on the professionalism and intelligence of the employees.

Encouraging innovators

Innovation requires innovative people -- individuals who are prepared to reject familiar work methods and try new, unproven alternatives that may fail. Not everyone is willing to do this. In fact, Don Hunt, an admirer of innovators, describes them ironically as "kind of sick, unhappy people. They innovate because they have to. It's inside of them. They would be much better off if they just did what other people did."

Organizational structure insures consistency. Consistency minimizes uncertainty and risk, and facilitates the performance of tasks. But innovation is unpredictable and risky. To encourage it,

one must have an environment which protects a pocket of inconsistency in a consistent organization. At AGMC, the Methods Lab provided a place for the initial development of the technologies. Early failures were shielded from outside eyes by a supportive and encouraging manager. As the technologies were developed, participation in technical conferences offered peer recognition of accomplishments. Once the technologies were ready to be used in production, seeing them used in regular production was further encouragement to the innovators.

Innovators are faced with two potential problems: change of management and loss of control over projects,

If there is a change in management, the innovators' work may be overlooked or terminated. This may discourage innovation throughout the organization.

The innovator wants to change current practice. Seeing the innovation used by others is psychological reward. But as an innovation is integrated into the organization's operations (institutionalized), it ceases to be the pet project of one or a few individuals. Ownership is transferred from the innovators to the organization. This can be a very painful process for the innovators, who may feel betrayed and unwanted. A similar phenomenon is experienced by many successful entrepreneurs, who must relinquish control over a business when it grows too large to be a one-person outfit. The difference between independent entrepreneurs and innovators inside an organization is that entrepreneurs begin with business control. But innovators may still suffer tremendously when a project becomes so successful that it is no longer theirs.

Innovators' work does not make them popular with everyone. Some people are jealous; others may feel that they have been forced to do things that they did not want to do by management superiors who supported the innovation. When support for innovators is withdrawn through management change or institutionalization, acts of retribution may occur.

There are no simple solutions to these problems, but innovators can be rewarded by being allowed to continue to innovate. When they have completed one task successfully, they should be rewarded with a new challenge -- perhaps one of their own choosing.

Experimentation

For an innovation to develop, it needs to be allowed to fail. Only through experimentation can an innovation be fine-tuned. The initial work must be sheltered, so the innovators will not be discouraged and their innovation will not be prematurely tagged as a losing proposition by other members of the organization. The ideal environment for the development of innovation is one that allows for mistakes to be made and corrected internally and successes to be publicized externally.

Implementation

Constant forward momentum is important for the application of a new technology. If an innovation becomes stalled, it may be difficult or impossible for it to move forward again. One of the many virtues of the matrix management system at AGMC was its ability to accelerate implementation of the various elements of the ODC-elimination technologies. The elimination of red tape through blanket agreements with customers and a blanket laboratory service agreement allowed forward motion to continue .

If an innovation does not become accepted as routine, standard practice, it will eventually be discontinued. The base-wide involvement in implementing the ODC-elimination technologies helped make them routine in the eyes of most of the employees. The technologies were and are felt to be part of the entire base, not of just one department. Management emphasized that the program was integral to the base. When the Innovations in American Government award was accepted in Washington DC, the Center's representation was based on chain of command. When the base commander presented the award in Newark, he stated that the award was being given to the whole Center. He told the assembled groups: "There are a variety of people on stage who represent the different groups involved. They are here representing you, because it is your award."

In many respects, institutionalization of an innovation is the most difficult step in the process. Excellent management and good timing are required to take an innovation from a small group of developers and make it the property of the entire organization.

A key part of institutionalization is spreading the knowledge associated with an innovation across the organization. If knowledge is not widely shared, the innovation may be discarded because it is not understood by its users. An innovation may baffle people who are unfamiliar with its operation, and they may for that reason reject it. Information that is held by only a few people can be lost through transfer of personnel to other positions.

The standard method for institutionalizing knowledge at AGMC has been procedural documentation -- technical orders (TOs) and utility training manuals (UTMs). There was much debate on whether sufficient detail was being provided in updated TOs and UTMs. The final decision was based on limited resources. Instead of specifying procedures for the cleaning of each product, a general cleaning procedure has been written up. The documentation of the general cleaning procedure should be sufficient as long as an organizational memory exists of doing certain things in certain ways. Examples include procedures for dealing with static electricity, properties of metals and epoxies that are dependent on initial processing, and immediate air drying of components to prevent water marks and flash rusting. See the technical section of this report for details. It is not possible to predict how the privatization process will affect technical memory at AGMC or in organizations using the same or similar technologies this report is intended in part to extend the organizational memory.

Diffusion of Knowledge

Potential users of AGMC technologies are diverse. They include international and local organizations, governments, and industries interested in new products and maintenance in electronics, precision cleaning, cleaning, and refrigeration. Determining which government or industry sites have been influenced by AGMC requires locating potential users of AGMC-pioneered technologies, determining what technologies they are using, and tracing AGMC's influence on them.

A certain amount of reinvention or adaptation would be required for the technologies at other sites (except perhaps for the electronic-component cooling and HFC refrigerants in environmental chambers). But earlier research in this field has found that there is a tendency for individuals or organizations that apply technologies developed elsewhere to exaggerate the significance of the modifications they have made, and they often consider the original source of technology as a provider of useful information, not as a technology provider.

The need for modification of technology to fit the specific needs of a site, coupled with the tendency to exaggerate the extent of modifications made, makes tracking the diffusion of AGMC's technologies difficult.

Detailed below is what has been done to diffuse technical information. It is worth noting that after all this effort, AGMC does not know whether these efforts have led to the adoption of its technologies elsewhere. The moral is that one can offer information and support to other locations, but may never know whether they have replicated the technologies.

Efforts to diffuse knowledge at AGMC included:

1. Hosting visits from or technical exchanges with

- representatives of French industry, May 1994
- Litton Systems
- UNEP Technical Solvents Committee
- military personnel as per request
- ODC elimination open house "work force recognition program", January 1996

2. Providing information by telephone

According to Captain Campbell, "We get some calls from industry and some from military -- some from GE this week -- and we got a call from a contractor that's done work out of Oklahoma

City, and I guess they're working a little bit with Robbins [Air Force Base], too." Chuck Davis has also received a variety of inquiries, but he says "It's hard to sit here and say to someone in San Diego...how you do these things [e.g., clean parts with unusual geometries] over the telephone...so we brought him in here and showed him."

3. Presentations at Conferences and Technical Papers

- "The Cyl-sonic Cleaner: Aqueous Ultrasonic Cleaning Using Biodegradable Detergents," July 1989.
- "Aqueous Cleaning of Instrumentation Bearing Assemblies," January 1990
- "GIT-1B and TG (Beryllium) End Housing Aqueous Cleaning Project Summary to Date," July 1990.
- Presentation at US/Singapore Conference on Alternatives and Substitutes to CFC Solvents on "A US Air Force Repair Center's Policy and Progress in Eliminating CFCs," September 1990.
- Request for information on CFC Reduction by General Viccelio (Deputy Chief of Staff, Logistics and Engineering), October 1990.
- The work at AGMC is used as a case study of ozone-friendly precision cleaning in an EPA publication, "Eliminating CFC-113 and Methyl Chloroform in Precision Cleaning," June 1991.
- "Precision Bearings Cleaned at AGMC," July 1991.
- "Aqueous Cleaning for Precision Bearings and Beryllium," November 1991.
- "Aqueous Alternatives to CFC-113 and MCF for Precision Cleaning of Inertial Systems and Components," December 1991.
- Presentation at the Joint Logistics Commanders Meeting, Brooks Air Force Base, TX on "Eliminating Ozone-Depleting Solvents in an Industrial Activity", February 1992.
- Presentation at the International CFC and Halons Alternative Conference, Washington, DC on "How One of the Largest Air Force Users Is Getting Out of CFC's," July 1992.
- Presentation at the Joint Services Data Exchange, Palm Springs, CA "Progress in Replacing Ozone-Depleting Chemicals for Precision Cleaning at the US Air Force's Aerospace and Guidance and Metrology Center," October 1992.
- "Degradation of Polybromo Fill Fluid," Physical Chemistry Laboratory, December 1992.
- "Experience and Initiatives in Replacing Ozone Depleting Chemicals for Precision cleaning at the US Air Force's Aerospace Guidance and Metrology Center," submitted to ASTM, 1993.
- Presentation at the XVth International Environmental Research Forum, Dayton "Alternatives to Ozone-Depleting Chemical-Dependent Test Equipment Components," August 1993.
- "The Use of Perfluorocarbons as Alternatives for Ozone-Depleting Chemicals at the Aerospace Guidance and Metrology Center- Some Considerations", Submission to EPA SNAP Program, August 1993.
- Presentation at the Maritime Environmental Symposium "Alternatives to Ozone-Depleting

Refrigerants in Test Equipment," October 1993.
- Presentation at International NATO/CCMS Conference, Brussels "A Proposal to Use Evidence from Successful ODC-Elimination Efforts to Reduce the Lead Time for Implementation of ODC-Solvent Alternatives," January 1994.
- Presentation at International Compressor Conference, Purdue "Alternatives to Ozone Depleting Refrigerants in Test Equipment," July 1994.
- Presentation at the International CFC and Halons Alternative Conference, Washington, DC, on "Instrumented Laboratory System for the Evaluation of Alternate Cleaning Technologies," October 1994.
- Center activity a success story at CFC and Halons Alternative Conference, Washington, DC, October 1994.
- "Application of More Environmentally Compatible New Technologies to Replace ODCs in the Repair of Inertial Guidance Navigation Systems" presented at the 22nd Joint Services Data Exchange, November 1994.
- *CFC, Halon News* article about a diagnostic tool developed with and in use at AGMC, "Now You Have a New Alternative to CFC-12," December 1994.
- *Precision Cleaning, The Magazine of Critical Cleaning Technology* article about AGMC's use of aqueous technology in cleaning, "Flowing Forward with Aqueous Technology," February 1995.

4. Involvement of third party laboratories - with the result that they gain expertise which they can offer elsewhere

- "Experimental Evaluation of the Corrosive Potential of Flux Residue Cleaning Agents," Battelle, January 1992.
- "Identification of Contamination Found Deposited on Gyroscope Ring," Battelle, April 1992.
- "Identification of Spots Found on the Surface of the Gyroscope End-Cap 3637," Battelle, June 1992.
- "A Method for Cleaning Performance Evaluation Using Stable Isotopes," Battelle, August 1992.
- "Experimental Evaluation of the Adhesive Degradation Potential of Aqueous Cleaning Processes", Battelle, January 1993.
- "Electronic Component Cooling Alternatives: Compressed Air and Liquid Nitrogen," Battelle, April 1993.
- "Identification of Biodegradable/Environmentally Compatible Methods for Epoxy Removal -- Phase I," Battelle, August 1993.
- "Advanced Technology Cleaning Methods for High-Precision Cleaning of Guidance System Components," Battelle, September 1993.
- "Alternatives to Ozone-Depleting Chemical Dependent Test Equipment Components - Topical report on materials compatibility," Battelle, September 1993.

Lessons Learned (strengths, weaknesses, and opportunities) from the AGMC Innovations

Management

Management can obtain tremendous efforts towards a goal if (1) the goal is seen by employees as worthy and (2) managers consistently place the goal over all other options. These strategies dissuade departments from trying to optimize their own performance at the expense of other groups.

Management can achieve the goal by setting direction and allowing employees at the operational level to make decisions. Management involvement is required only if conflicts or uncertainties arise which cannot be resolved at the lower levels.

System Stresses

External stresses often stimulate innovation. Examples of external stresses on AGMC included:

1. Elimination of access to needed process input - ODC-elimination through international protocols on AGMC.
2. News release by the President and growing expectations from the DOD and Air Force, based on AGMC's early successes.
3. Threat of base closing, which encouraged personnel to demonstrate their potential, aiming at cancellation of the closure decision or making themselves more attractive to alternative employers.
4. Limited financial resources, especially early in the program, which encouraged personnel to take creative approaches to problems (e.g., looking for low-cost alternatives and borrowing equipment for the first cleaning centers).

Initiating Innovation

Innovations require time and nurturing to become useful and successful. Keep options open and if at first you don't succeed, try, try again. Do not, however, assume that one technology will eventually work. The more fall-back plans and options available, the better. Wait patiently for success to arrive, but be prepared for failure.

Maintaining Forward Momentum

It is important that conflicts between departments and individuals be brought out into the open, so

that differences in opinion can be resolved. Conflicts were quickly addressed at AGMC. The results did not always please everyone, but disputants appreciated the fact that the issues were discussed and efforts were made to accommodate differing points of view and concerns.

Forward momentum is vital to keep people focused on the goal. Quick movement is necessary for a program to maintain forward momentum. AGMC moved quickly, cutting red tape with:

1. Blanket agreements with customers for approvals and for laboratory services.
2. Scrounging equipment from around the facility to save money and avoid the purchasing process.
3. Use of the "Ozone" stamp and a modified matrix management to assign tasks without delays.
4. Tracking ODC use closely to locate areas of concern, prevent rejection of adopted innovations, and to communicate forward progress.
5. Involving individuals who took responsibility for problems and were willing to put in as much time and effort as required during key stages in the program.

Institutionalizing Innovation

Institutionalization of an innovation (making it part of an organization's routine) is important to insure it has a lasting effect on the organization. AGMC encouraged institutionalization by:

1. Involving as many people as possible as early as possible.
2. Transferring program needs from a department or area to the entire organization.
3. Giving time for institutionalization to occur. (Even after old methods are no longer in use, an innovation is not necessarily adopted.)
4. Allowing the meaning of a successful program to evolve over time as the understanding of the potential and expectations for the innovation or program change.
5. Documenting information in writing or disseminating it to many people in the organization (thereby developing an organizational memory). (If only a few people understand a technology and they leave, the technology may cease to function and be prematurely abandoned.)

Diffusion

Knowledge diffusion is feasible, but do not expect credit or recognition. It can be difficult to diffuse knowledge to competing organizations, because they lose by face relying on outside sources.

Measurable

The measurables were developed to allow for a simple way of tracking the institutionalization and/or rejection of various parts of the ODC-Elimination program over time. Forms are to be completed every six months.

To be filled out by contractor:

Percentage of product lines being cleaned with water
Percentage of units being cleaned with water
Number of new products lines introduced
Quantity of new products introduced

For each change in current cleaning process:

Product Identification	Anticipated Volume	Length of Contract (in Years)	Old Solvent Used for Cleaning	New Solvent Used for cleaning	Reason for Change

For each new p, oduct and cleaning process:

Product Identification	Anticipated Volume	Length of Contract (in Years)	Solvent Used for Cleaning (0S30, **DI** water, etc.)	Gross Value per Year of This Product	Reason for Solvent Choice

Measurable

Product lines phased out in this **calendar year**:

Product Identification	Average Volume	Length of Contract (i Years)	Solvent Used for Cleaning (0S30, **DI** water, etc.)	Reason for Change

To be filled out by the customer (Ogden and Oklahoma City):

Please outline any changes in the past six months relating to implementation, proposed implementation, or testing to change the cleaning process at Newark, Ohio, **Please include**:

1. **Approved testing of alternative chemicals**
2. **Changes from existing technology (e.g., water to OS30)**
3. **Improvements made to cleaning process**
4. **Issues or concerns with existing processes.**

For products that your facility has introduced in the last six months to Newark, Ohio, please fill in the table:

Product Identification	Anticipated Volume	Length of Contract (in Years)	Solvent Used for Cleaning (0S30, **DI** water, etc.)	Gross Value per Year of This Product	Reason for solvent Choice

Measurable

R/C6810PPF5052	**Performance Fluid 5**
R/C6850PAK-225	**Asahiklin AK-225**
R/C9150POS-10	**OS-10 Silicon Liquid**
R/C9150-POS-30	**Silicone OS-30 Fluid**

Creating an Environment Which Does Not Prevent Innovation

The likelihood that specific innovations will survive changes in upper management depends on two factors: the breadth of support in the rest of the organization and the existence of external pressures. A middle manager who champions a project must be aware that changes in upper-level management can downgrade or terminate the project. But middle managers are not powerless to protect the innovative activity that they are responsible for and have been nurturing. The likelihood of project continuity after changes in management or organization structure can be increased if there is broad support in the organization or external pressure for it.

In 1985 the seeds of the ODC-elimination program did not have broad support. As a result, a change in management was sufficient to temporarily suspend the program. By 1993, the program had supporters in all areas of the organization, including nontechnical areas like contracting and finance. But if top management support had ceased at this point, the support of individuals across the organization would have provided sufficient momentum through informal channels for continuing the program.

In the 1990s external pressure for eliminating ODCs existed. This pressure was probably not sufficient to motivate change. Some other organizations using ODCs stockpiled solvents and waited for an easy alternative to be invented. But AGMC personnel were kept focused on the external pressures by on-going communication from interested parties. External attention and interest in AGMCs program would have made it difficult to shelve or terminate the project. Through its hard work and widely communicated advances AGMC established itself as a leader in the field in 1990. Its acknowledged leadership placed psychological pressure on management to maintain its leadership position. AGMC was in competition, and it was winning. It is unlikely that management will withdraw support from a winner.

There was competition inside AGMC: it competed against itself. However, it is advisable that competition between parts of an organization remain as friendly as possible. If competitors are made to feel that there are the winners and losers, that may resist technology transfer to other branches of the organization, reduce mutual assistance between various parts of the organization, focus on keeping score rather than on moving forward, and thus undermine other parts of the organization.

If an organization competes against itself and does not continue to perform well, it will lose face. That danger can motivate people to work together to protect the honor of the organization. Management can encourage this cooperation by regularly participating in conferences, making written or public statements of intent, and initiating competition between parts of the organization.

Organizational Goals

The direction of an organization is set at the top, but the goals must flow downwards to the people working at the lower levels. They must decide how these goals can be met and what is needed to meet them. When AGMC's goal of eliminating ODCs was established, the engineers working on the project were allowed to determine what the best technologies were and how best to implement them. Even the work arrangements of project team members were allowed to

Encouraging Innovation

Once an environment has been created that allows innovation to occur, the next step is to encourage innovation. The following emerged as key elements of a successful innovation process:

- Responding to external pressure
- Establishing management strategy
- Encouraging the innov ators
- Encouraging experimentation
- Implementing new technologies
- Institutionalizing innovations
- Diffusing innovations

External Pressure

External pressures constantly pushed the project and its participants forward. As outside pressure on participants increased, forward momentum was easier to maintain. Cost savings were not sufficient to drive innovation, but knowledge that the chemicals the facility relied on depleted the ozone layer led to the realization by forward-thinking individuals that dependence on these chemicals would not be sustainable in the future. Positive experiences with the energy conservation program led individuals like Don Hunt to believe that it would be possible to reduce reliance on ozone-depleting chemicals. A climate of tightening waste-disposal regulations assisted in building support for the initiation of the early elements of the program (chemical reclamation). The passing of the Montreal Protocol in 1987 ensured that use of ODCs would be short-lived at best. Increasing pressure was placed on the facility as ODC phase-out deadlines were accelerated by the 1990 London and 1992 Copenhagen amendments to the Montreal Protocol.

AGMC's reports on its initial work on aqueous cleaning brought interest and attention from the Department of Defense and the EPA. This recognition encouraged the innovators to continue to innovate. As more impressive technical results were obtained, AGMC came under more pressure to produce results. External interest in innovation generated a positive feedback loop of increasing support for the innovators and their work.

AGMC negotiated with their customers to obtain blanket permissions for testing and implementing ODC-free cleaning processes. It is worth noting that the missile customers and aircraft customers came to an agreement with AGMC shortly after the news release from President Bush's press secretary. Agreements were signed one month and three months later, respectively.

evolve in a natural way. By the end of the project, the responsibilities of the project team had become distributed according to the personalities and preferences of team members.

Reducing System Delays

System delays must be reduced or eliminated. Otherwise an innovation can die the death of a thousand cuts: each wound is minor, but together the tiny wounds can be fatal. The use of the "Ozone" stamp was instrumental in ensuring the smooth processing of innovation-related paperwork. Agreements were made with customers so that each change could be handled in a consistent, mutually agreed-upon manner. Standard reporting channels were modified to simplify the performance of tasks. For example, the pipe fitter received directions directly from project engineers (In the past, an engineer submitted a work request to a supervisor, and the supervisor chose the personnel and the start date.) The supervisor became involved only if there were difficulties, as when a pipe fitter was asked to do two or more projects at the same time. The role of the supervisor was transformed from controller and manager to coach.

Placement of Personnel

In many organizations the roles that people are expected to fill do not suit their abilities, personality or temperament. Conformity to roles provides stability and consistency in an organization, but to obtain superior performance and innovation, one must allow more leeway for people to determine the best ways to apply their abilities to get things done. Many of the managers at AGMC expressed the need to allow people to be themselves and use their own unique sets of abilities. "I think we were able to have key people on key roles, at the right place, at the right time," says Colonel Renaud. The placement of these people was no accident: "You don't necessarily take the natural progression for selecting new people for new jobs. I refuse to accept that my choices are limited....When you have a job opening, you've got to say, 'Who's the best person to fill that job?'....You have to capitalize on their strengths." According to Colonel Renaud,"Don Hunt was the key role. I think [he] is the key throughout the whole period as a catalyst." Hunt also payed close attention to the strengths and personalities when placing individuals in new positions: "I handpicked some very innovative and creative people from those available."

To create an environment where innovation can occur it is important to have:

- Management support of innovation
- Identification of goals at the top of the organization, leaving details to people closer to the actual task
- Minimization of red tape
- Placement of people in positions that match their personalities and abilities, and encouraging people to be themselves.